Adam Para,
Fermilab, April 26, 2010

T-1004
INITIAL RESULTS

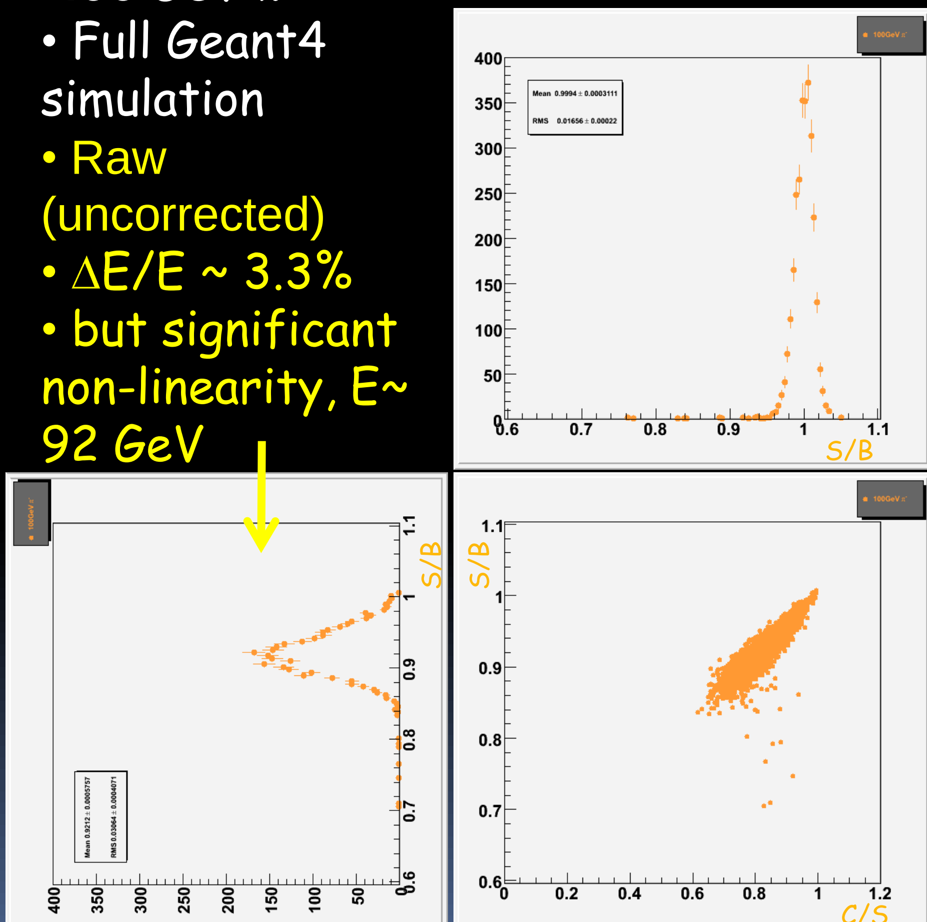
Total Absorption Dual Readout Calorimetry R&D

Fermilab, Caltech, University of Iowa, Argonne National Laboratory, Fairfield University, CERN, INFN Trieste/Udine, INFN Roma, Shinshu University and University of Cyprus

Phase 1 principal participants: Burak Bilki and Ugur Akgun(Iowa), Diego Cauz and Giovanni Pauletta (Udine), Fotios Ptochos (Cyprus), Erik Ramberg, Paul Rubinov, Hans Wenzel and Adam Para (Fermilab)

TAHCAL at Work: Single Particle Measurement

- 100 GeV π-
- Full Geant4 simulation
- Raw (uncorrected)
- $\Delta E/E \sim 3.3\%$
- but significant non-linearity, E~ 92 GeV



After dual readout correction, correction function (C/S) determined at the appropriate energy:

- Linear response: S/B=1 for all energies
- energy resolution $\Delta E/E \sim \alpha/\sqrt{E}$ (no constant term)
- $\alpha \sim 12$-15%

Motivation

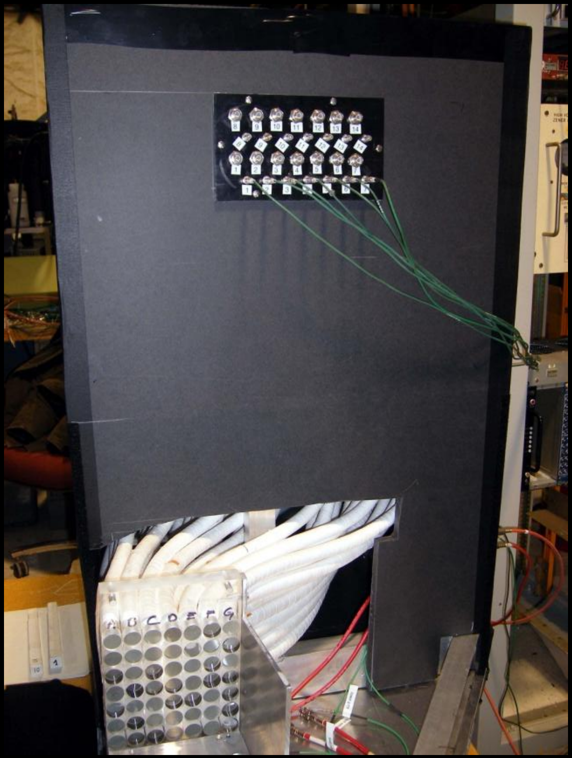
- Total absorption hadron calorimeter with dual readout (scintillation + Cherenkov) appears (on paper, in the simulation) to offer a possibility for hadron/jet calorimetry with the energy resolution approaching ~10%/sqrt(E)
- Development of inexpensive dense scintillators and compact photodetector is necessary to construct a real-life detector
- Practical problems of relative calibration of a segmented calorimeter and of light collection and of scintillation and cherenkov components may prove to be limiting factors. The goal of T1004 is to provide some experimental input in these areas.

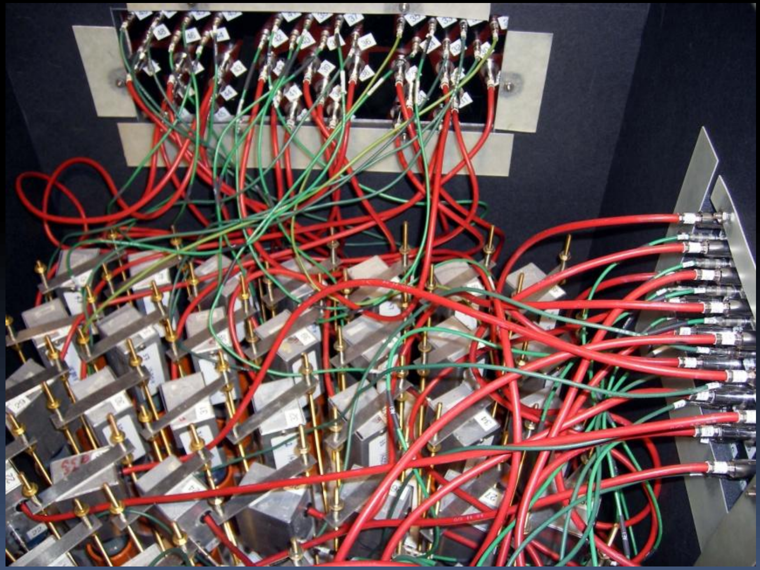
Two Components of the Test Beam Program

- EM calorimeter with different crystals, different photodetectors, different geometries. Calibration of a segmented calorimeter. Position and angle measurement.
- Single crystal exposure. Different crystals, different photodetectors, different geometries, different surface treatment, different filters. Separation of Cherenkov and scintillation. Light collection, uniformity. Cherenkov light yield, Angular dependence of the Cherenkov signal.

EM Calorimeter, version 1.0

- PbWO4 crystals (Iowa), former CMS test beam calorimeter
- 7 x 7 crystals array, read out via light guides and PMT's. Beam along the crystal axis
- Crystals of varied quality (yellowness), check the energy resolution as a function of the crystal quality
- Future developments:
  - equip with SiPM's, check the energy resolution SiPM vs PMT
  - Couple PMT's directly , rotate by 90 degrees, 6 x 9 matrix, study the position and angle measurement






13
14
15
16


21
22
23
24


29
30
31
32


46
47
48
49

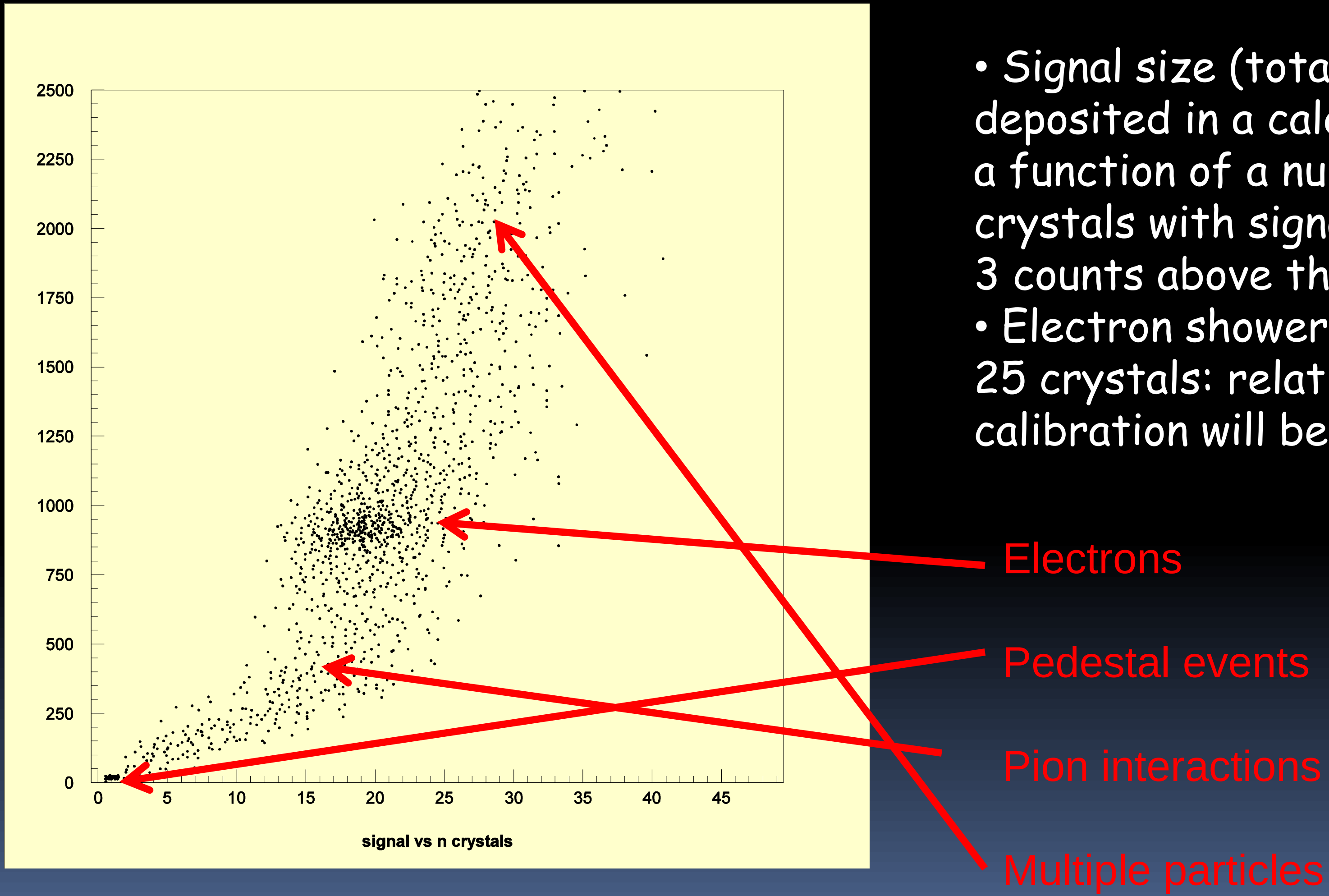
Useful Data Taken

- Front face of the calorimeter illuminated with muons.
- (Mostly electron) beam, 4 and 2 GeV directed to the center of the inner 3 x 3 array
- Signals of 120 proton beam registered in 2 phototubes and 20 SiPM,s at various locations on a surface of 5 x 5 x 5 cm BGO crystal (from Caltech). Visible and UV filters used. Crystal oriented at 0, 30 and 60 degrees with respect to the proton beam.

Known Problems and Issues

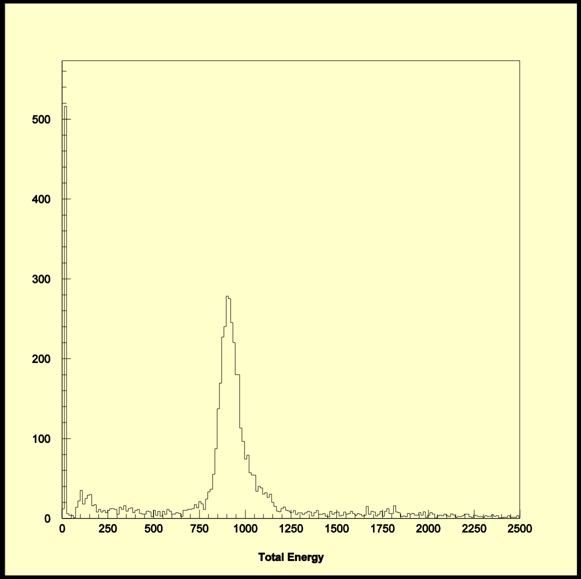
- ADC (Lecroy 2249W) have 'beam on' pedestal dependent on the history of the input pulses. Quite serious effect in a central tower (i.e. the one beam is directed towards)
- One Cherenkov dead, the other has only one PMT. This PMT is very noisy (until the last day of running). The ADC reading out the Cherenkov particularly vulnerable to the floating pedestal problem
- Beam spread not well known, probably bigger that the resolution of the calorimeter
- CAPTAN system working marginally. Very little of particle position information available, if any.

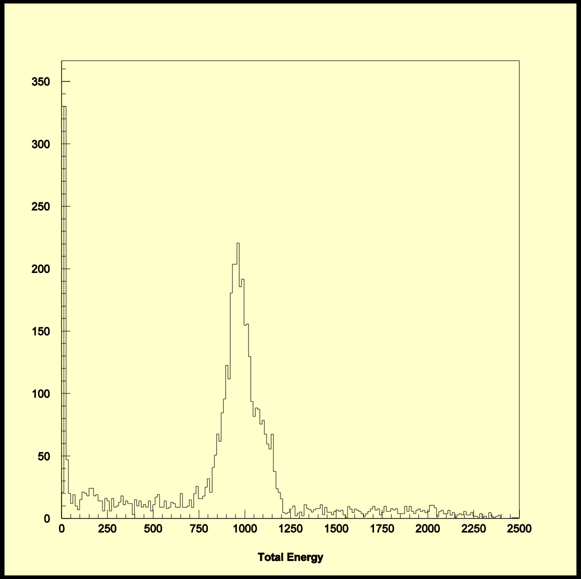
Electron Showers

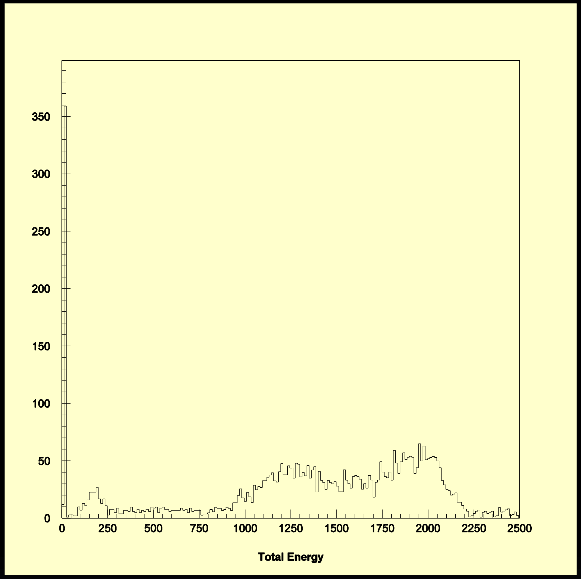


- Signal size (total energy deposited in a calorimeter) as a function of a number of crystals with signal more than 3 counts above the pedestal
- Electron showers involve 15-25 crystals: relative calibration will be important

Raw observed signals, different crystals (central)







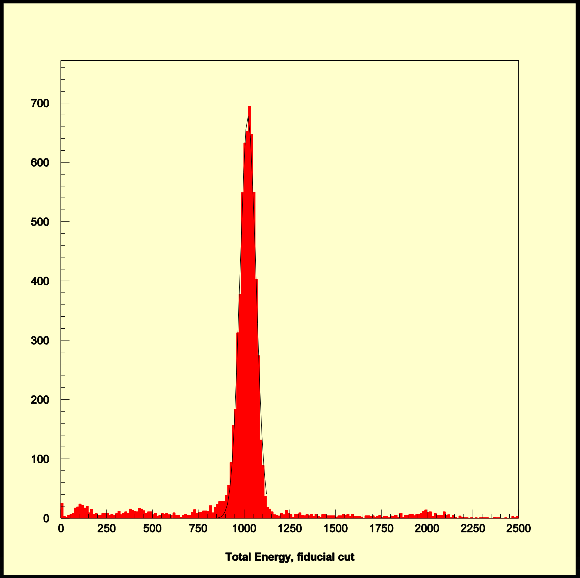
Tower 25 Tower 32 Tower 18

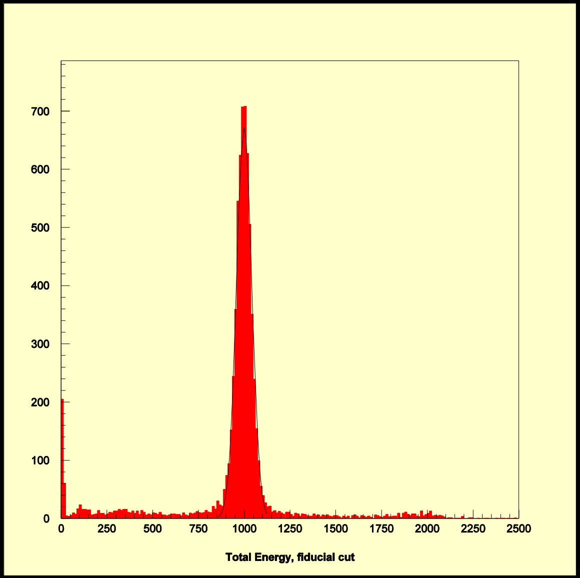
Relative calibration is crucial to attain good energy resolution

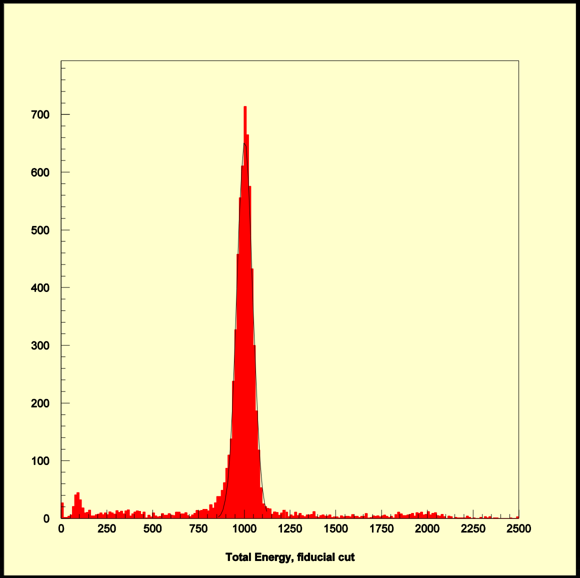
Relative Calibration

- It is clear that to attain the ultimate energy resolution it is necessary to equalize the response of all crystals. Finding a robust procedure for the cross-calibration is a primary goal of the studies.
- Some possible calibration methods:
  - Method 1: use muons to illuminate crystals one-by-one, use the average or peak
  - Method 2: throw all electron runs together, fit 48 constants of relative calibration to minimize the resulting width (very time consuming and unstable fitting)
  - Method 3: select one beam position, use 5x5 array, fit 24 relative calibration constants by minimizing resolution. Repeat for different beam positions
  - Method 4: select one beam position, fit. Add the second beam position, fit together, add third beam position, fit.. Etc..etc..
- <u>If everything is done correctly and understood, all methods should give consistent results, within their systematic errors</u>

Electron calibration (an example)







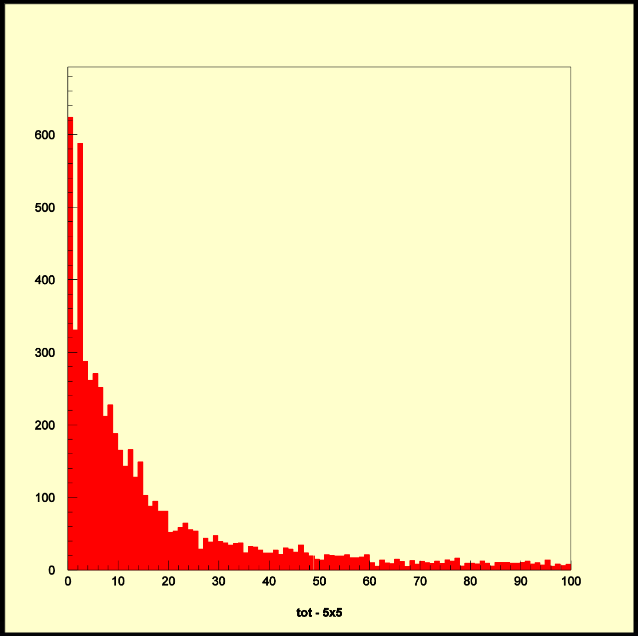
Tower 25
Mean = 1021.2
σ = 43.25

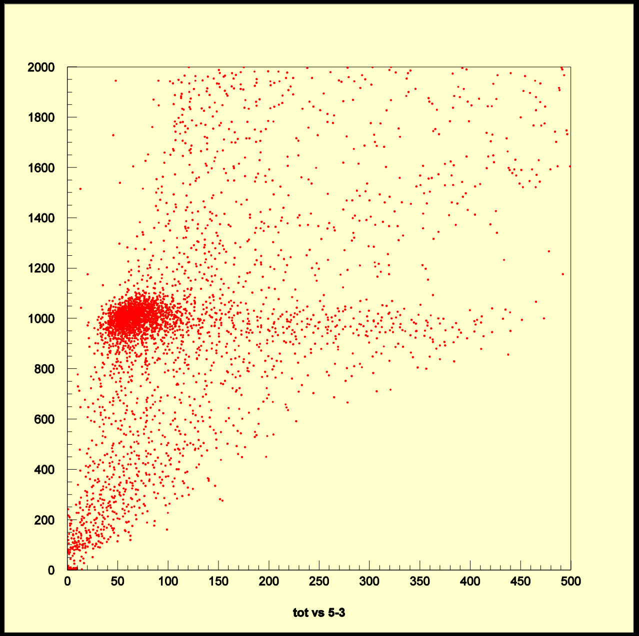
Tower 32
Mean = 999.40
σ = 41.81

Tower 18
Mean = 1002.6
σ = 43.02

Relative cross-calibration good to ~ 1%. Energy resolution at 4 GeV is ~ 4.3% (probably dominated by the beam spread).

Spatial Development of EM Showers

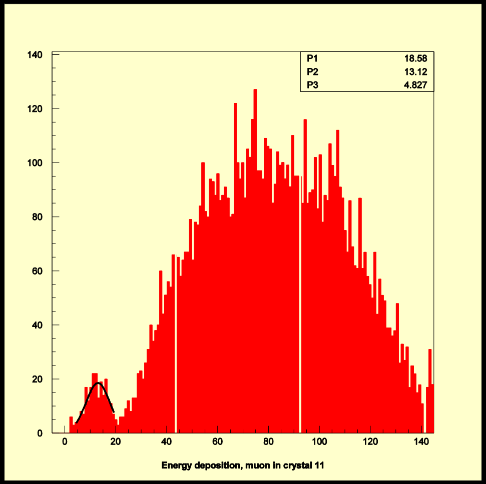


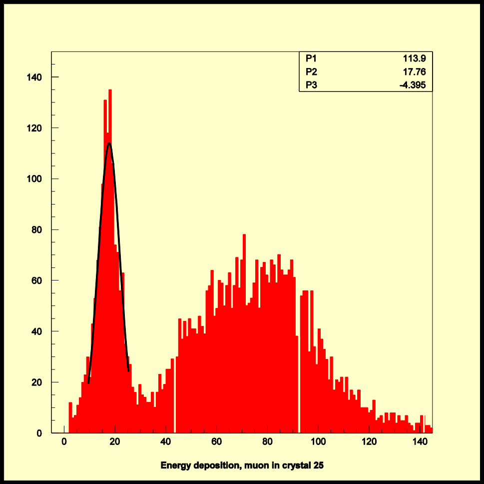


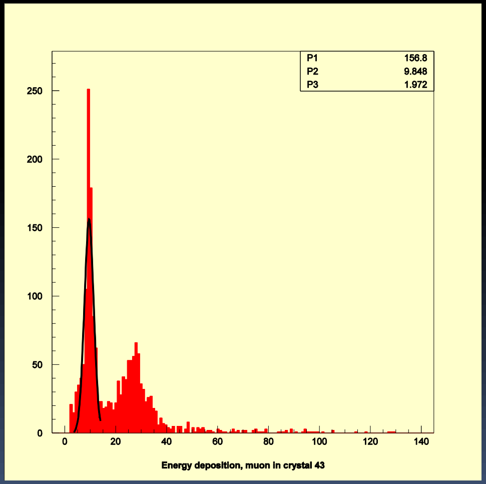
Difference between the signal in the entire detector and the 5x5 array. For electrons, some 1-2% of energy is deposited outside the 5x5 array

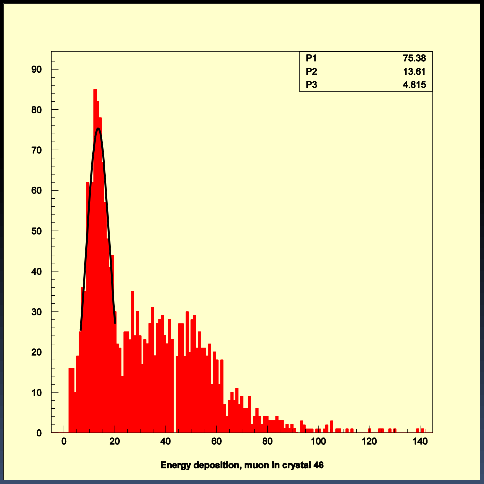
Total signal vs difference between 5x5 and 3x3 arrays (both centered on the crystal with maximal energy). For showers centered on a crystal some 5-10% of energy is deposited outside 3x3 array

Muon Calibration (An Attempt)



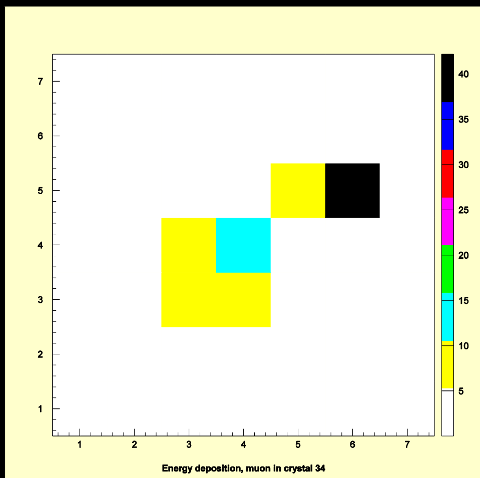




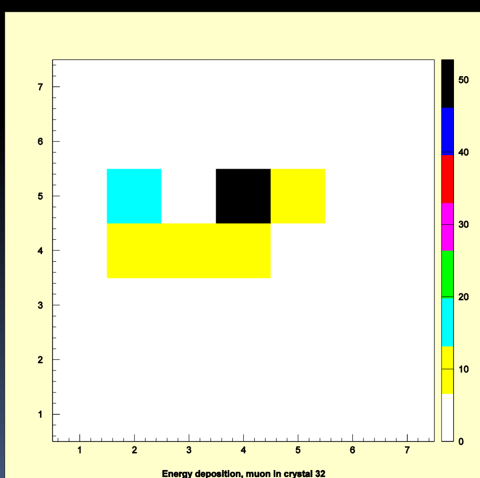


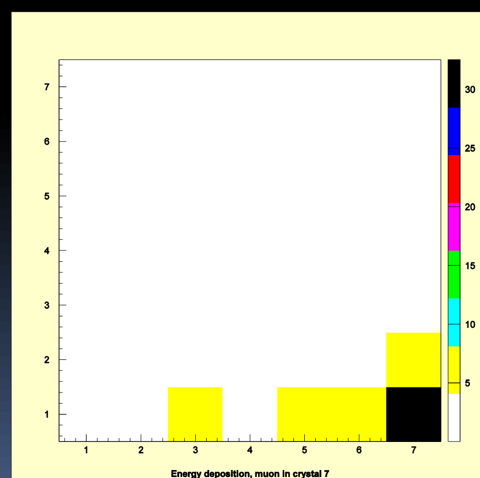
- Observed signals in a single crystal, when this signal is the largest one in the event.
- 'Muon signal' is clearly visible (in most of the crystals) but the observed signals are dominated by the light generated in the bundles of light guides behind the crystals.

Cross Talk in the Light Guides

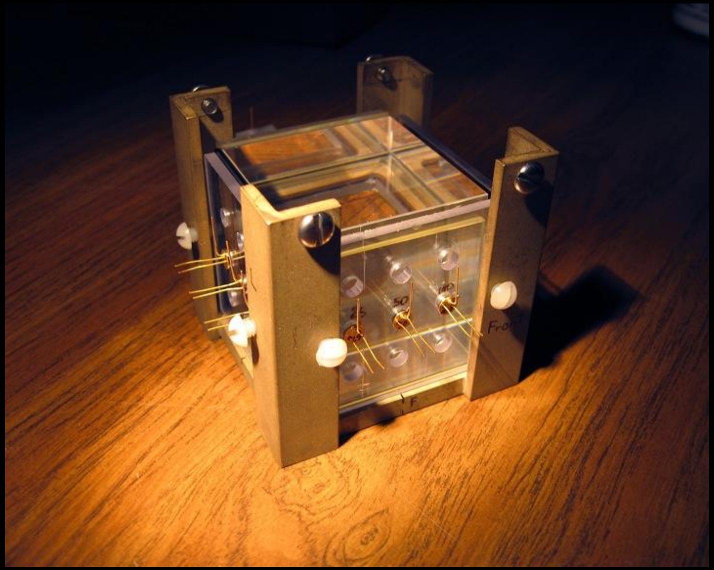


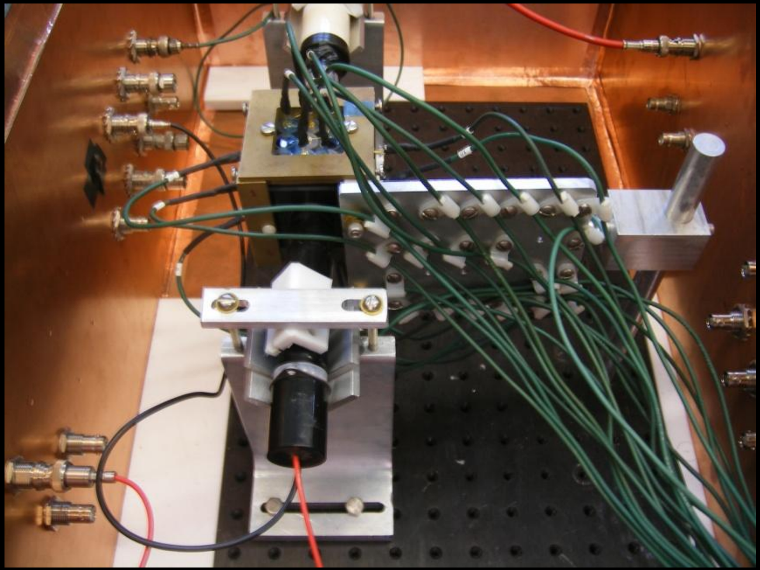
Signals observed in various towers when the maximal signal in the event is located in a 'black' tower.
All the events taken at the same time with the muon beam illuminating the detector.
Clear proximity pattern, consistent (roughly, no detailed analysis) with the routing of lightguides





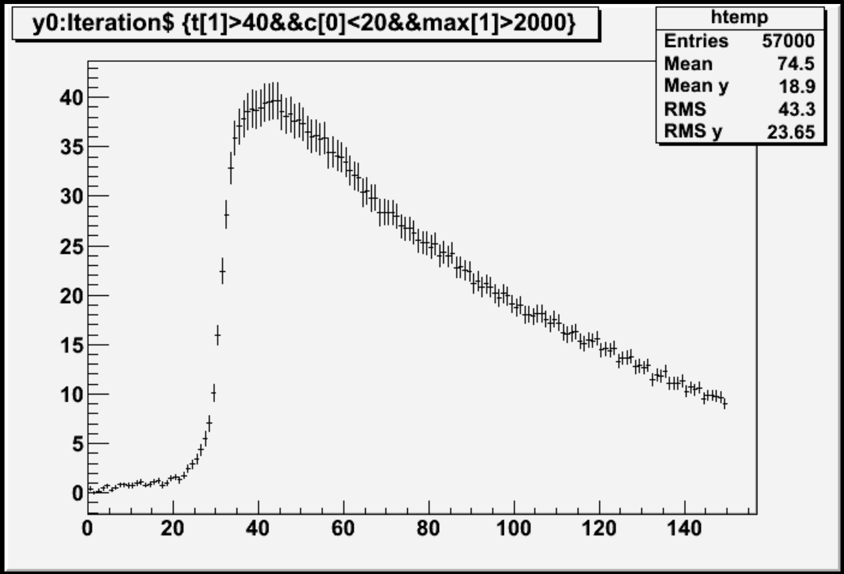
Single Crystal Setup

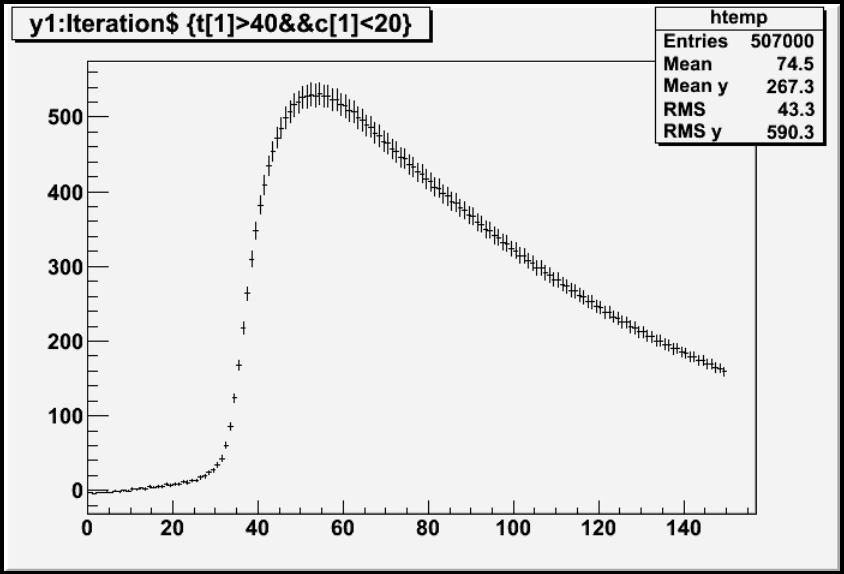




- BGO crystal (from Caltech)
- visible and UV filters
- two PMT's
- 20 Hamamatsu SiPM's
- TB4 readout boards (P. Rubinov)

Data (Analysis Just Started)





Average pulse shape recorded in PMT with UV filter (5 ns bins)

Average pulse shape recorded in PMT with visible light filter

- Both PMT's show similar fall time, characteristic of BGO (300 nsec). This is an evidence for significant comoponent of scintillation below 400 nm
- 'UV' PMT shows a significant 'prompt' component
- Quantitative analysis, including the SiPM,s position and angle dependence coming soon..

Conclusions

- Segmented crystal calorimeter has significant cross-calibration potential. It can be even used to identify various flaws and imperfections of the real detector.
- Even with very crude initial cross-calibration it is possible to reduce the spread of responses of different crystals from more than a factor of two to 1-2%
- The resolution of the order of ~4% at 4 GeV can be attained, likely dominated by the beam energy spread
- This is just a beginning: a lot of careful and interesting studies need to be carried out. Come and join!